

Committee on Earth Observation Satellites  
17<sup>th</sup> Plenary Meeting  
Colorado Springs, Colorado  
November 19-20, 2003

CEOS/17/Agency Report:  
Roshydromet

**Item 19.5**

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**RUSSIAN ENVIRONMENTAL SATELLITES: CURRENT STATUS  
AND DEVELOPMENT PERSPECTIVES**

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**Summary and purpose**

The document presents an overview of Russian environmental satellite program including current status, plans for future developments as well as mission objectives and applications. It considers also the current status of the Roshydromet ground segment developed for the acquisition, processing and distribution of satellite data and products. The main purpose of aforementioned satellite systems development as well as operational and research activity in Roshydromet is to use satellite data and derived products in various application areas, including operational meteorology, NWP, hydrology, agrometeorology. Some examples of derived satellite products are demonstrated and their applications are discussed.

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**ACTION PROPOSED**

The meeting is invited to take note of the information contained in this document.

Please note: It is planned that the illustrative materials (Fig. 1 - 15) will be presented on CD and in hard copy directly at the CEOS 17 Plenary meeting (due to the large volume of these materials.)

# ***RUSSIAN ENVIRONMENTAL SATELLITES: CURRENT STATUS AND DEVELOPMENT PERSPECTIVES***

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## **INTRODUCTION**

The document presents an overview of Russian current and future environmental satellite systems. In the framework of national weather satellite system modernization the efforts are focused on the development and manufacturing the next generation of polar-orbiting (METEOR series) and geostationary (ELECTRO series) meteorological satellites. These satellites are expected to be launched not later than 2005, 2006 year respectively. Their payload composition together with short description of some basic instruments performance characteristics are given.

Along with the support and modernization of operational meteorological satellite systems, the development of environmental satellites is being continued. The brief description of forthcoming oceanographic satellite SICH-IM core payload (joint undertaking between Russia and Ukraine) is presented.

Next year Rosaviakosmos plans to launch two polar orbiting satellites for detailed Earth surface monitoring, namely RESURS-DK and MONITOR. Basic instruments payload of these satellites is depicted.

The last part of report concerns current status of Roshydromet ground segment, including generation and distribution of various satellite products. Some examples of satellite derived products are demonstrated, with sharing them for operational monitoring and climate studies.

## **POLAR ORBITING SATELLITES OF METEOR SERIES**

Russia is now developing next series polar orbiting meteorological satellites. The first polar orbiting satellite of this series named METEOR-3M N 1 has been successfully launched in December 2001. It is worth to note that unlike preceding satellites of METEOR series, the high resolution imager MSU-E of visible range is embarked on board METEOR-3M N 1. The next satellite of this series that should be launched not later than 2005 is designed for operational providing of hydrometeorological and heliogeophysical information. The primary mission objectives of existing and forthcoming METEOR satellites are quite similar to those specified for NOAA and EPS/METOP satellites and include:

- atmospheric temperature & humidity soundings for NWP support (global and regional coverage)
- imagery of clouds and land/ocean surfaces (global and regional coverage)
- ozone and other trace species monitoring
- sea ice and snow coverage monitoring
- support of climate monitoring
- providing heliogeophysical information
- data collection and location

In order to meet the requirements of the users (mainly in the field of operational meteorology and climate monitoring) the future METEOR spacecrafts being launched on sun-synchronized orbit will carry as mandatory payload the imagers of visible (VIS), infrared (IR) and microwave (MW) range as well as IR and MW atmospheric sounders.

In summer 2002 the original satellite sketching design has been rather seriously revised. It is proposed to develop and to launch in the years 2005 and 2007 two satellites on the base of unified and rather heavy platform (of «Resurs» type) with a suite of operational and experimental instruments. Both these satellites should provide the flight demonstrations of key systems and be the predecessors of operational and complete METEOR satellite. Moreover both new spacecrafts will be equipped with supplementary instruments. In particular, it is planned to develop the locator (radar) «Severjanin» and multichannel optical scanning device KMSS of medium resolution (~ 50 m) on board the first new satellite. The implementation of these instruments should ensure substantial extension of forthcoming METEOR mission objectives. The final characteristics of the first satellite named «Meteor-M» have been specified in the end of 2002. The table 1 summarizes the instruments embarked on board this spacecraft. Below a brief overview of basic METEOR-M instruments is presented.

## **METEOR-M sounding instruments**

In full analogy with NOAA, MetOp satellites the payload composition of METEOR-M satellite should consist of the suite of 2 sounding instruments providing remote sensing of three-dimensional fields of temperature and humidity of the atmosphere (one is MW sounder and other is IR sounder).

### ***MW sounder/imager MTVZA***

One of the major sensors of sounding instruments suite is multichannel microwave (MW) conical scanning radiometer MTVZA. The primary mission of MTVZA measurements that is similar to NOAA/AMSU instrument is to provide all-weather atmosphere temperature and humidity sounding capabilities to support numerical weather prediction schemes of global and regional coverage.

The MW radiometer MTVZA, being designed and manufactured by the Space Observations Center, Rosaviakosmos is based on the technology of combining in space and time the multi-spectral and polarization measurements. The MTVZA operating frequencies are located both in the transparent bands of 18.7, 33, 36.5, 42, 48, 91.61 GHz as well as in absorbing lines of oxygen 52-56 GHz and water vapor 22.235 and 183.31 GHz. The important feature of instrument is that it provides the common field of view for imaging and sounding channels.

At the middle of February 2002 the performance tests of MTVZA instrument have been started in the framework of METEOR-3M N 1 commissioning phase. In May 2002 the scanning mechanism of MTVZA has failed.

During the performance tests the algorithms for preprocessing and calibration of MTVZA raw data have been developed and implemented. The calibration procedure consists of two steps: «internal» calibration, i.e. transformation of raw signals to antenna temperatures  $T_a$ ; absolute calibration, i.e. transformation  $T_a$  to brightness temperatures  $T_b$ , using statistical regression approach. Along with this the temperature profile retrieval scheme has been developed and tested using linear eigen vector regression algorithm and actual MTVZA measurements.

The general conclusion of MTVZA data analysis is as follows: the satellite MTVZA measurements are reliable and are suitable for remote sensing of temperature profiles. Basing on the above performance tests the necessary technical modifications and refinements of MTVZA instrument design have been carried out and the next MTVZA device is installed on board SICH - 1M satellite (see Section 4).

### ***Advanced IR sounder IRFS-2***

The second component of METEOR-M sounding system is IR atmospheric sounder IRFS-2 that is being designed as multi-purpose Fourier transform spectrometer.

The IRFS-2 operable spectral range extends from 5 to 15  $\mu\text{m}$ . while spectral resolving power is about  $0.5\text{ cm}^{-1}$  (after apodization). Now the manufacturing of space-borne IRFS-2 instrument is underway.

It is pertinent to note that along with described atmospheric sounders (intended to be operational) the development of the supplementary sounding instrument called Radiomet (see table 1) and

based on radio occultation principles is now under consideration. The evident advantages of such instruments are the low cost and mass.

### **METEOR-M imaging capabilities**

Along with atmospheric sounding system the payload composition of METEOR-M satellite should consist of the suite of imaging instruments providing imagery of clouds and land/ocean surfaces. The major sensor of this suite is multichannel scanning radiometer MSU-MR, see table 1. This instrument has 6 channels in VIS/IR and is designed as cross-track scanning radiometer with basic characteristics similar to those for NOAA/AVHRR/3. The multichannel scanning unit (named KMSS) is proposed as supplementary imaging instrument. This device should provide the imagery in 4 VIS channels (0.45-0.9  $\mu\text{m}$ ) of medium resolution (100 m).

The imaging mission in MW should be accomplished by MTVZA instrument. In full analogy with well known MW imagers SSM/I (DMSP) or MW sounder AMSU (NOAA) or imager/sounder SSMIS the successful implementation of MTVZA should ensure the retrieval of so called non-sounding products, namely total precipitable water, cloud liquid water (both over ocean), near-surface wind speed, instantaneous rain rate as well as surface temperature, sea ice concentration and snow cover.

Imaging mission will be also performed by supplementary "active" sensor i.e. radar (named "Severjanin"). This instrument is now under development. Its operating frequency range is 9500-9700 MHz, the swath band is about 450 km. Two modes of spatial resolution i.e. minimum or low (0.7 x 1.0 km) and optimum or medium (0.4 x 0.5 km) are foreseen. These characteristics will be finalized before the end of 2003.

### **FUTURE GEOSTATIONARY METEOROLOGICAL SATELLITE GOMS/Electro N 2**

In 2001 Rosaviakosmos together with Roshydromet and other Russian State departments committed a tender on development of future GOMS/Electro geostationary meteorological satellite that will meet requirements of national and international users community. As a result of the tender the satellite manufacturer has been selected and principal characteristics of spacecraft and its payload have been specified. GOMS/Electro N 2 satellite being relied on 3-axis stabilized platform will be designed to allow operational observation of cloudiness and Earth surface, conducting heliogeophysical measurements and maintaining National Data Collection System (see Fig.1).

The satellite main instrumental payload is the optical imaging (line-by-line scanning) radiometer (so called MSU-G). It should provide image data in three visible (VIS) and near IR channels (VNIR) and 7 IR channels. Spectral characteristics of channels are presented at table 3. The spatial resolution (sampling distance) in subsatellite point will be about 1 km for VIS and 4 km for VNIR and IR channels respectively. A new earth image will be provided every 30 min. Along with this the more frequent regime is envisaged (every 10-15 min) for selected MSU-G image fragments and channels. In the framework of design finalization the possibilities to implement supplementary channels 11, 12 (see table 2) should be investigated.

It is worth to note that providing accurate on-board calibration for IR and solar channels (which is envisaged in the sketch design) remains an issue. Another issue is ensuring about 10 years of nominal lifetime for the spacecraft and its basing systems (including MSU-G) In case of successful solution of listed problems the MSU-G instrument with full ensemble of 12 channels should provide the information similar to that of MSG/SEVIRI.

The second important mission rationale of GOMS/Electro N 2 is the development and maintaining of national data collection system (DCS). According to current planning the developed DCS should be capable to operate with about 800 national DCP platforms.

To conclude brief overview of GOMS/Electro design, note that the spacecraft GOMS/Electro N 2 will be also equipped with a transponder for the geostationary Search & Rescue service of the COSPAS/SARSAT organization. Similar to Meteosat, MSG this payload should be implemented subject to some constraints, namely, no interference with the meteorological missions and minimum mass are required.

## OCEANOGRAPHICAL SATELLITE SICH-1M

Forthcoming oceanographical satellite SICH-1M is a joint undertaking between Russia and Ukraine. Actually, it appears to be the extension and modernization of well-known satellites of "Okean-01" series. The spacecraft "SICH-1M" is planned to be launched in the first quarter of 2004 on sun synchronous orbit at an altitude of 650 km. The table 3 summarizes the basic instruments payload of the SICH-1M satellite. Besides listed instruments the spacecraft is equipped with 3 Space-Ground downlink radio lines: 8 GHz (intended for MSU-EU, global MTVZA-OK as well as MSU-M+RM-08 data transmission); 1.7 GHz (intended for local MTVZA-OK or MSU-M+RM-08 data transmission); 137 MHz (intended for APT transmission of MSU-M+RM-08 data).

Roshydromet is appointed to be one of the SICH-1M operators responsible for data acquisition, processing and distribution. The processing and utilization of SICH-based measurements by RLSBO (Side Looking Radar) and MTVZA (microwave imager/sounder) is of great importance for various operational applications within Roshydromet activities. One of key instruments on board SICH-1M is the side looking radar RLSBO. It is quite similar to analogous instruments on board previous "Okean-01" satellite. Roshydromet and SRC Planeta have a big experience in the analysis and application of radar imageries for monitoring of sea ice, see example below (Section 5). Along with this the modernized imager/sounder MTVZA-OK is of substantial importance for operational and research activities. First of all the launching of this instrument should ensure the performance tests of refined technical design of MTVZA (keeping in mind forthcoming launch the METEOR-M spacecraft with similar MTVZA sensor on board). Besides it is worth to note, that the MTVZA-OK will provide some new interesting and powerful capabilities for more efficient studies of the ocean-atmosphere system. By combining optical and MW observations in the same instrument, some beneficial advantages for determining geophysical parameters are foreseen. Both atmosphere temperature and moisture profiles, SST and near-surface wind speed, as well as ocean color and processes within active ocean layer will be observed concurrently. Along with this the uncertainties that often exist when multispectral observations are taken from different instruments are removed through MTVZA-OK capabilities.

## ENVIRONMENTAL SATELLITES RESURS-DK AND MONITOR-E

### *RESURS-DK1 satellite*

The new Russian satellite RESURS-DK1 is developed by Rosaviakosmos to provide the detail observations of the Earth surface local areas in VIS band.

Rosaviakosmos intends to launch this satellite in 2004.

The satellite RESURS-DK1 will operate on near-circular orbit at an altitude about 350 km with the orbit inclination about 65°. This satellite's lifetime is planned not less than 3 year.

The new optoelectronic imager, installed on this satellite, will operate in panchromatic and multichannel modes with the following characteristics:

- *Panchromatic mode*

Spectral band	0.58 – 0.8 µm
Spatial resolution	1 m
- *Multichannel mode*

Spectral bands	0.5 – 0.6; 0.6 – 0.7; 0.7 – 0.8 µm
Spatial resolution	2 - 3 m
- Swath width                      28.3 km

## *MONITOR-E satellite*

Rosaviakosmos intends to launch the first satellite of the new MONITOR series in 2004.

MONITOR-E satellite is destined for environmental monitoring in regional scale. This satellite will provide Earth observations in VIS spectral band with high spatial resolution.

The satellite MONITOR-E will operate on sun-synchronous circular orbit with the orbit inclination 97.5° at an altitude about 540 km.

The instruments payload of this satellite includes two imagers with the following characteristics:

- *Panchromatic imager*

Spectral band	0.58 – 0.8 $\mu$ m
Spatial resolution in nadir	8 m
Swath width	93.8 km
  
- *Multichannel imager*

Spectral bands	0.54 – 0.59; 0.63 – 0.68; 0.79 – 0.9 $\mu$ m
Spatial resolution in nadir	20 m
Swath width	160 km

It is planned to organize the data direct broadcast to receiving centers of Roshydromet for MONITOR-E data use in operational hydrometeorology and in the framework of environmental monitoring, including hazards monitoring.

## **ROSHYDROMET CORE GROUND SEGMENT CAPABILITIES, SATELLITE PRODUCTS AND APPLICATIONS**

The major components of the Roshydromet's ground segment are three Main Regional satellite data receiving and processing Centers at different locations: European (Moscow, SRC PLANETA), Western-Siberian (Novosibirsk) and Far-Eastern (Khabarovsk). The ground segment also includes the network of APT, HRPT and WEFAX receiving stations. Roshydromet's main satellite Center SRC PLANETA (Moscow) performs a scientific and methodological management and coordinates the activities of the above-mentioned acquisition Centers and stations. The radiovisibility circles of these Centers cover the whole territory of Russia as well as Baltic States and major part of Europe (see Fig 2).

Present SRC PLANETA receiving facilities provide on a regular basis the data acquisition from geostationary (METEOSAT-7 and METEOSAT-5, GOES-E, GOES-W, GMS via METEOSAT-7) and polar-orbiting (Meteor-3M N 1, NOAA series, EOS/Terra/Aqua) satellites.

The communication facilities of "Planeta" created on the basis of widespread network of various communication channels (including a link through the satellite, WWW technology via INTERNET) enable a reliable and operational transmission the information to the users and facilitate the data real-time access.

Current activities within Roshydromet and SRC Planeta are concentrated on providing all operational functions and services (satellite data acquisition, processing, generation and dissemination of products) as well as on the preparation to the forthcoming satellites data handling and fulfillment of their mission objectives.

The architecture of future METEOR and GOMS-Electro ground segments (hardware, software, communication links) is envisaged to be based on the physical facilities of Roshydromet ground segment major components. Now the technical design and development of next METEOR and

GOMS-Electro N 2 ground segments have been commenced. Some elements of future METEOR ground segment have been tested in the framework of METEOR -3M N 1 commissioning phase.

Below the progress in satellite products generation is briefly outlined with sharing them for various applications.

### **Cloud imagery and cloud analysis**

Cloud imageries and cloud cover parameters continue to be one of the key output products of both polar orbiting and geostationary meteorological satellites. Fig 3, for example, is a randomly chosen mosaic of infrared images over Eurasia constructed from data provided by Meteosat 7, Meteosat 5 and GMS. Similar mosaics are generated daily on the basis of various compositions of imageries provided by 5 geostationary satellites (see Fig.4). Along with these some “quantitative” cloud products are derived daily from satellite data, including estimates of cloud cover fraction and cloud top temperature and height (CTTH). Now the validation of CTTH is being continued.

### **Snow cover and ice concentration maps**

The measurements of microwave scanning radiometers like imager SSM/I (DMSP) or sounder AMSU (NOAA) can be utilized for generation of so called non-sounding products. In particular, it's possible to identify and discriminate snow and ice cover over the full range of snow conditions (excluding melting snow and coastal ice). The refined methodology ensures the discriminations of melting snow and coastal ice. The example AMSU (NOAA-16) – based snow and ice cover map for Europe is given at fig 5. Such maps are provided regularly (on experimental basis) using AMSU NOAA-HRPT data during all seasons. As follows from validation tests, the above maps are in a good correspondence with conventional data and satellite coastal ice images.

Another non-sounding product is the identification of precipitation zones and instantaneous rain rate estimation (both over land and sea). Fig 6 is an example of such product, generated from AMSU-A (NOAA-16) data. Comparison with conventional data confirms the reliability of rain rate estimates, but further trials and verifications are required.

### **Forest fires detection**

Meteorological satellites are capable to monitor large-scale smoke plums and forest fires. Fig 7 shows large-scale forest fires in East Siberia region, detected from AVHRR/NOAA data. More detailed monitoring of forest fires is provided via the analysis of high spatial resolution satellite images. Fig 8 a, b demonstrate examples of dangerous fire detection in Moscow region (summer 2002), using MSU-E Meteor 3M N 1 imagery with spatial resolution of 45 m as well as forest fires and smokes in Irkutsk region defined from MODIS/Terra imagery (spatial resolution is 250 m).

### **Sea ice operational mapping**

In order to detect ocean and sea ice and to characterize its features (that is of significant importance for many applications) it is necessary to combine high and low resolution information from various satellite-based active and passive sensors, namely from SLR, SAR as well as MW and optical imagers. SRC Planeta has many years experience in the interpretation of radar imageries (SLR's on board “Okean” satellites) and operational generation of ice maps. At present, because of absence this source of information, the operational sea ice monitoring is carried out using visible and thermal imageries provided by NOAA, Meteor-3M N 1 and Terra satellites. Fig 9, for example, is a randomly chosen ice map for the “inner” Azov sea constructed from AVHRR/NOAA, MODIS/Terra and Meteor-3M N 1 data. This product of relatively low resolution is generated not automatically, but with human analyst intervention. More detailed information on ice cover can be derived using high resolution images provided by MSU-E imager from Meteor 3M N 1, see Fig 10. Here is presented the ice cover for Volgograd reservoir. The example of ice conditions within part of Baltic Sea derived from MODIS imagery (channel N 1, resolution is 250 m) is shown at Fig 11. These examples illustrate how data from different satellite systems really appear to be a valuable tool for monitoring of ice cover.

## Monitoring of sea water and snow cover pollution

The multispectral high-resolution images from Meteor 3M N 1 can be utilized for regular detection of pollution areas on snow cover around big industrial centers as well as for investigation of pollution propagation within sea coastal zones. The example of snow cover pollution in Southern Ural region and the imagery of pollution propagation in Eastern coastal zone of Black Sea are given at Fig.12, 13 respectively.

## Climatological studies of sea ice cover in Arctic

Since the moment of the first Okean series satellite launch in 1983 ("Okean-1500") SRC Planeta carries out satellite monitoring of ice conditions in Arctic Region using side looking radar (SLR) data. Long-term archive of OKEAN satellite radar data allows to perform a number of research and application tasks that require long-term sets of observation data, in particular, for climate change researches. The thematic maps of multiyear and first year ice distribution in the winter periods of 1983-2000 for Western sector of Arctic Region (east part of Barents sea and Kara sea) were generated (Fig. 14). At present the re-processing of long-term archive of OKEAN satellite radar data is being performed for Russian sector of Arctic. The example of multiyear and first year ice cover map for this region is presented at Fig. 15.



**Table 1****Basic instruments payload of the METEOR-M**

<b>Instrument</b>	<b>Application</b>	<b>Spectral Band</b>	<b>Swath-width (km)</b>	<b>Resolution (km)</b>
<b>MSU-MR</b>	Global and regional cloud cover mapping, SST, LST, ...	0.5 – 12.5 $\mu\text{m}$	3000	1 x 1
<b>KMSS multichannel scanning unit</b>	Earth surface monitoring	0.4-0.9 $\mu\text{m}$	100	0,1
<b>MTVZA imager/sounder</b>	Atmospheric temperature and humidity profiles, sea surface wind	10.6-183.3 GHz (26 channels)	2600	12 – 75
<b>IRFS-2 advanced IR sounder</b>	Atmospheric temperature and humidity profiles	5-15 $\mu\text{m}$	2000	35
<b>Severjanin (active radar)</b>	Ice monitoring	9500-9700 MHz	450	0.7 x 1.0
<b>Radiomet* (radio occultation unit)</b>	Atmospheric temperature and pressure profiles.			

**Table 2****MSU-G spectral channel characteristics**

<b>NN</b>	<b>Channel</b>	<b>Spectral range</b>	<b>S/N for VIS NEDT for IR</b>
<b>1</b>	Vis 0.6	0.5 - 0.65	> 10
<b>2</b>	Vis 0.7	0.65 - 0.8	> 10
<b>3</b>	Vis 0.8	0.8 - 0.9	> 7
<b>4</b>	IR 3.7	3.5 - 4.01	< 0.35 K
<b>5</b>	IR 6.7	5.7 - 7.0	< 0.75 K
<b>6</b>	IR 8.0	7.5 - 8.5	< 0.28 K
<b>7</b>	IR 8.7	8.2 - 9.2	< 0.28 K
<b>8</b>	IR 9.7	9.2 - 10.2	< 1.5 K
<b>9</b>	IR 10.7	10.2 - 11.2	< 0.3 K
<b>10</b>	IR 11.7	11.2 – 12.5	< 0.3 K
<b>11*</b>	Vis 1.6		>3
<b>12*</b>	IR 13.4		< 1.8 K

**Table 3****Basic instruments payload of the SICH-1M satellite**

<b>Instrument</b>	<b>Application</b>	<b>Spectral Band</b>	<b>Swath-width (km)</b>	<b>Resolution (km)</b>
<b>RLSBO – Side Looking Radar</b>	Sea ice mapping, snow coverage, Earth surface Monitoring	3.2 cm	450	1,3 x 2,5
<b>RM-08 MW imager</b>	Sea ice mapping	0.8 cm	550	25
<b>MSU-M Optical imager (low resolution)</b>	Earth surface monitoring	4 channels: 0.5 – 0.6, 0.6–0.7, 0.7–0.8, 0.8–1.1 $\mu\text{m}$	2000	1.7
<b>MSU-EU Optical imager (high resolution)</b>	Earth surface monitoring	3 channels: 0.5 – 0.6, 0.6–0.7, 0.8–1.1 $\mu\text{m}$	45	0,045
<b>MTVZA OK Combined MW and optical imager/sounder</b>	Atmospheric temperature and humidity profiling, monitoring of ice and snow, sea surface wind speed TPW, CLW, precipitation, ocean colour	22 MW channels: 6.9; 10.6; 18.7; 23.8; 31.5; 36.7; 42.0; 48.0; 52-57; 89.0; 183 GHz. 5 channels in VIS/IR: 0.37-0.45; 0.45-0.51; 0.58-0.68; 0.68-0.78; 3.55-4.0 $\mu\text{m}$	2000	20 – 200 for MW, 1.1 for VIS/IR
<b>“Variant” unit</b>	Heliogeophysics Space environment monitoring	-	-	-